Fishery intensification in small water bodies

A review for North America

by
John F. Moehl Jr
and
William D. Davies
Department of Fisheries and Allied Aquaculture
International Center for Aquaculture
and Aquatic Environments
Auburn, Alabama, USA

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PREPARATION OF DOCUMENT

This is one of a series of documents that deals with the general theme of the intensification of management of fisheries in small water bodies. It is part of a world-wide activity of the FAO Inland Water Resources and Aquaculture Service to compile and disseminate information that can be used to improve fisheries benefits from small, multi-purpose water bodies. This document reviews the research and management experience in North America. Other reviews soon to be published, or nearing completion, are based on experience in Africa. For current information on the activity and on the publications available, write to the Chief, Inland Water Resources and Aquaculture Service, Viale delle Terme di Caracalla, 00100 Rome, Italy.

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ABSTRACT

Management strategies for fish populations in small impoundments are reviewed with consideration given to intensification techniques applied throughout the United States and Canada. The concept of balance in fish populations is used as a basis for illustrating the importance of maintaining desirable predator/prey relationships through stocking and harvest regulation of keystone predators. Generally, harvest levels for predators are reduced when species diversity and structural complexity of the environment are increased. Intensification is also achieved by enhancing water fertility through liming and fertilization. Case studies are presented representing contrasting climatic regions of North America while demonstrating similarities in management style. Principles and practices presented in this paper should be adaptable to the management of fisheries in small water bodies over a wider geographical range than discussed.

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1. INTRODUCTION

1.1 Definition of Small Water Bodies

The focus of this paper is fishery management in small water bodies in the United States and Canada. While research and extension activities associated with small water bodies in North America have been directed toward creating sport fisheries, the principles can be applied to most extensive fishery or aquacultural systems based on predator/prey relationships.

The paper is organized as a review of principles of aquatic system management for improved fish production, and as a presentation of case studies of small impoundment management in the Southeastern, North Central, and Northwestern regions of North America. The principles represent technology that is transferrable to other geographic areas. Case studies demonstrate the application of these principles in North America. By virtue of the diversity of their application, they confirm that it is principles, not practices, that can be adopted by fishery managers outside North America.

Water bodies considered are natural and man-made freshwater impoundments with surface areas equal to or less than 80 ha. This size corresponds to water bodies routinely managed for fishery intensification in the Southeastern United States.

Natural impoundments are formed when water is retained in depressions. Impoundments can be built by constructing dams, or through excavation. Embankments of most impoundments are earthen. Water sources are surface runoff, diversions from streams or rivers, or wells. Natural impoundments typically have no means of controlling inflow or outflow. Constructed impoundments generally have a spillway or drain and may have structures for regulating flow such as diversion ditches and standpipes.

Small water bodies are established in the public and private sectors. The former are frequently called public fishing lakes; the latter farm ponds. For the present discussion, all are referred to as impoundments. Ponds of commercial fish farms, or other intensive aquacultural activities, are excluded from this discussion.

In addition to physical aspects, impoundments are defined by factors including species diversity, fertility, and structural complexity of the aquatic habitat. The goal of fishery management is to control these factors to produce a harvestable surplus while maintaining a dynamic equilibrium within the system.

Surplus production in a sport fishery is usually negatively correlated with species diversity and structural complexity of the system. It may or may not be enhanced by increasing levels of fertility. Management options depend as much on these factors as on size, ownership, or location of the water body.

1.2 Use and Relative Importance of Small Impoundments

Many impoundments have multiple uses. They can be built for soil and water conservation, livestock watering, irrigation, fire protection, wildlife habitat, recreation, landscape improvement, and sport fishing (Bennett 1952, SCS 1971, SCS 1982a).

Weigmann and Helfrich (1992) noted that, in the United States, impoundments of less than 12 ha "constitute one of the most abundant and popular aquatic systems for sport fishing." They reported that, in 1985, 9.9 million individuals fished for 117 million days in small, artificial impoundments. Table 1 lists the area covered by small impoundments in the United States, by state. As defined by the United States Department of Agriculture's Soil Conservation Service, small water areas are impoundments less than 16 ha and perennial streams narrower than 200 m. In 1982, the total small water area in the United States was approximately 4 million hectares. Of this total, 47 percent were located in 15 Southeastern states (SCS 1982b).

Dendy (1963) characterized impoundments in the contiguous United States as being natural or man-made, public or privately managed, and containing cold or warm water. For water bodies of 4 ha or less, 1.5 million productive impoundments were reported in 1960 with a total surface area of 700,000 ha. Of recorded impoundments, roughly 97 percent were man-made, warm water, and privately managed.

From this discussion, it is apparent that there is no standardized water area corresponding to small impoundments. Small is a relative term, defined to suit the user's needs. Our demarcation of small as being 80 ha or less is based on the applicability of fishery management practices. Management techniques described here may be suitable to larger bodies of water, but their application is often impractical or not cost effective. Management implies control, and waters larger than 80 ha are characteristically difficult or excessively expensive to control.

1.3 History of Impoundment Management

An understanding of the history of North American small impoundment management is important to interpret current management practices. Several key individuals have played a significant role in the evolution of fishery management techniques applied to small impoundments. Practices developed by Swingle and Bennett serve as the foundation for understanding fishery dynamics in small water bodies. Subsequent work served to refine these basic principles, but the early works remain the underpinning for fisheries management in small water bodies.

Table 1. Small water areas in the United States, by state (SCS 1982b).

State	Water Area (000 ha)	State	Water Area (000 ha)
Alabama*	124.6	Nebraska**	87.2
Arizona	7.5	Nevada	7.6
Arkansas*	109.8	New Hampshire	23.6
California	134.6	New Jersey	24.4
Colorado	58.1	New Mexico	25.1
Connecticut	19.4	New York	117.0
Delaware	4.4	North Carolina*	112.4
Florida*	171.2	North Dakota***	71.7
Georgia*	162.7	Ohio**	80.4
Hawaii	4.9	Oklahoma*	139.1
Idaho***	28.7	Oregon***	60.4
Illinois**	138.2	Pennsylvania	91.6
Indiana**	83.1	Rhode Island	4.0
Iowa**	100.6	South Carolina*	71.3
Kansas**	122.0	South Dakota***	77.2
Kentucky*	82.4	Tennessee*	81.4
Louisiana*	191.1	Texas*	285.4
Maine	61.5	Utah	12.0
Maryland	25.6	Vermont	17.6
Massachusetts	29.4	Virginia*	88.9
Michigan**	105.4	Washington***	59.1
Minnesota**	145.2	West Virginia*	36.6
Mississippi*	149.6	Wisconsin**	111.7
Missouri*	138.4	Wyoming***	33.8
Montana***	120.4	Caribbean	8.6

* Southeastern region

** North Central region

*** Northwestern region

Initial efforts to manage impoundments for improved fish yield began in the United States in the early 1900s. Dyche (1911) described fishery management in impoundments in Kansas and Embody (1915) in New York. The latter author presented a natural systems approach to management where composition of the entire aquatic community was controlled, including fostering aquatic macrophytes to serve as "safe havens" for juvenile fish. Both authors proposed stocking a number of fish species and forage organisms to replicate as closely as possible the biotic complexity of natural systems.

Alternatives to the natural systems approach were proposed by Bennett (1943) and Swingle (1949) working in Illinois and Alabama, respectively. They concentrated on less complex, more manageable communities, identifying strategies involving control of predator/prey relationships using largemouth bass-bluegill systems. Their approaches differed, however, on how to exert this control. While Swingle focused on management to produce the maximum amount of harvestable fish, Bennett sought to produce the maximum amount of harvestable bass (Wenger 1972).

Swingle (1950, 1952) suggested control by managing the ratio of predator to prey. He recommended stocking fingerling largemouth bass as predator and bluegill as prey at the appropriate time and rate to achieve "balanced populations," where crops of harvestable fish are satisfactory year after year. Populations in balance have the ability to reproduce where some young serve as forage for predators while others recruit to replace those individuals lost to harvest and natural mortality. "Balance" is a management concept that relates to the structure of fish populations and the function of its components.

Bennett (1962) did not accept the concept of sustainable balance in fish populations. He believed prolific forage fish populations could not be controlled by predation alone and would ultimately overpopulate the impoundment. He recommended stocking both adult and juvenile fish to intensify predation and to promote a dominant year class of largemouth bass.

With this historical background, the next sections examine management of small impoundments. In Section 2, we summarize basic principles of fishery production in small water bodies. These apply to impoundments in North America and elsewhere. In Section 3, we describe the diversity of the North American setting, presenting case studies of fishery management representing different climatic zones.

2. PRINCIPAL PRODUCTION CONCEPTS

2.1 Abiotic Factors

The objective of fishery management in small impoundments is to regulate fish production to achieve sustained yields of harvestable-size fish. Yield refers to weight of fish harvested per unit area (i.e. kg/ha). It is partly a function of abiotic and biotic factors influencing the productivity of the aquatic system. The degree of management that can be imposed upon these factors determines the amount of intensification possible.

Abiotic factors are independent variables over which the fishery manager has little or no control. They relate to the geographical location and micro-climate of the impoundment. Included are temperature as a function of elevation and latitude; precipitation; and water and soil chemistry.

2.1.1 Temperature, elevation, and latitude

Temperature is one of the most important factors affecting fish growth. Growth increases with increasing temperature to a maximum and then declines rapidly. Within these limits, metabolism and food requirements increase with increasing temperature (Moyle and Cech 1988). For every 10° C increase in water temperature, metabolic rate doubles and oxygen demand increases. Concurrently, as temperature increases, the oxygen carrying capacity of water decreases, making less oxygen available for increased metabolic activity (Piper et al. 1982).

For different fish species, there is an optimum temperature for growth as well as minima and maxima above or below which growth slows. Maxima are frequently of concern for coldwater species and minima for warmwater fishes. Trout tolerate short intervals above 27° C, but die if exposed to extended periods above 23° C. Largemouth bass, however, express satisfactory growth and reproduction only when temperatures are above 22° C (Everhart and Youngs 1981).

Temperature is inversely correlated with elevation and latitude. Latitudinal effects vary with species. Modde and Scalet (1985) examined growth rates of largemouth bass and bluegill from Montana to Oklahoma, representing northern and southern latitudes of the United States. They found a significant inverse relationship between largemouth bass growth and latitude. By contrast, no significant relationship was found for the bluegill populations studied. Southern populations had higher numbers of large largemouth bass. Furthermore, largemouth bass predation on bluegills was more effective at more southern latitudes. Slower growing northern largemouth bass in balanced populations were found to be smaller than their counterparts in the south.

2.1.2 Precipitation

Precipitation is directly or indirectly the source of water for impoundments. As rainfall supplies water for impoundments, water losses occur through evaporation. Evaporation is positively correlated with temperature and solar radiation. Evaporation varies from less than 50 cm/year in cooler northern regions to more than 250 cm/year in hot southwestern areas (Figure 1). Additional losses occur through seepage. Seepage is determined by soil type and the quality of dam construction. Seepage rates may vary from less than 20 cm/year to more than 1,000 cm/year (Boyd 1982).

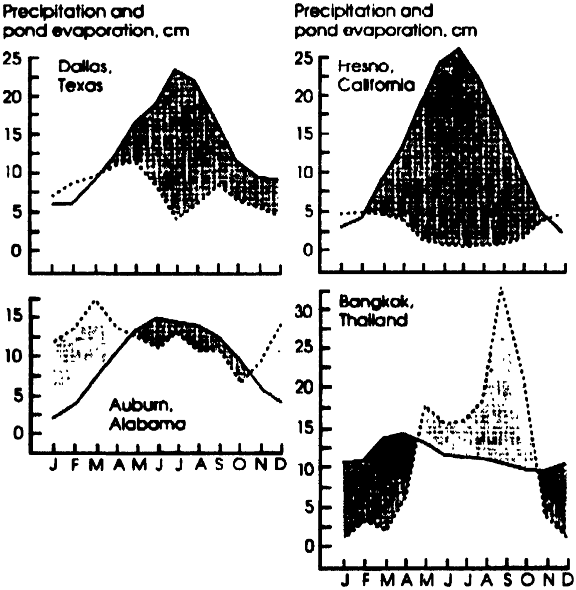

Figure 1. Relationship of precipitation and evaporation for different climatic regions (Boyd 1990).

A water budget for an impoundment considers total water inflow and outflow. Rainfall plus water added equals evaporation plus seepage and storage.

For many impoundments, direct precipitation and runoff from watersheds provide all water. For adequate year-round water storage in the southeastern United States, 6 to 15 ha of watershed are required for each hectare impounded (Boyd 1985). Figure 2 illustrates the general relationship between watershed area and impoundment volume across regions of the United States.

2.1.3 Water and soil chemistry

The chemical composition of water varies considerably among regions. Several indices are used as indicators of water chemistry. The complete array of ions in a water sample is measured as total dissolved solids. Concentrations of divalent metal ions are measured as total hardness. Concentrations of carbonate and bicarbonate are referred to as total alkalinity. Total alkalinity commonly ranges from below 5 mg/liter to more than 500 mg/liter. Hydrogen ion concentrations are expressed as pH. Typical pH values of impounded waters range from 5.0 to 10.0.

In impoundments, alkalinity and pH are linked through photosynthesis. These parameters affect the amount of carbon dioxide available for photosynthesis and subsequent fish production. Relative concentrations of dissolved carbon dioxide, carbonate, and bicarbonate depend on pH. The pH fluctuates during the day as photosynthesis increases with increasing sunlight.

The degree of pH change varies with alkalinity as illustrated in Figure 3. Waters with higher alkalinities are better buffered against radical changes in pH. Alkalinities of 20 to 300 mg/liter and pH values of 6.5 to 9.0 favor fish production. Figure 4 indicates pH affect on fish populations (Boyd and Lichtkoppler 1979, Boyd 1990).

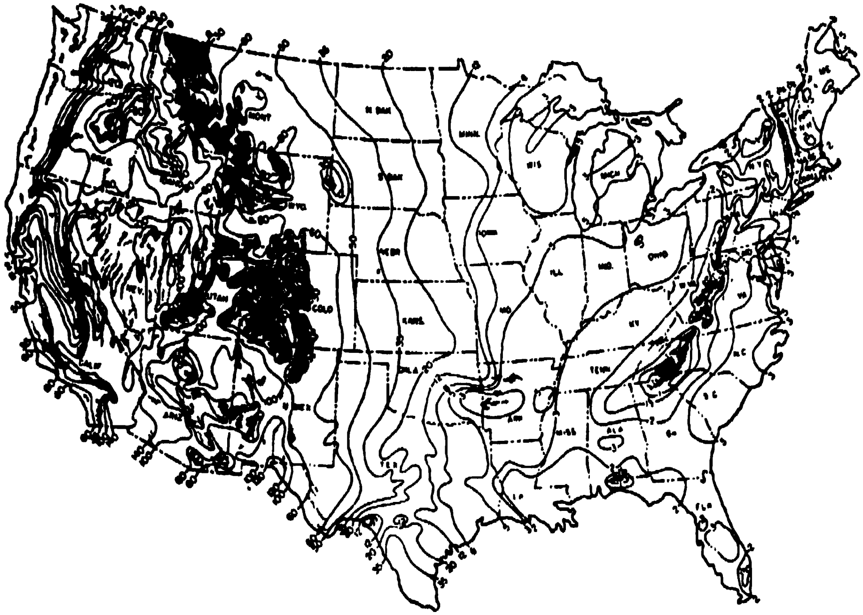

Figure 2. Ratio of watershed to impoundment area, in acres, for different regions of the United States (SCS 1971).

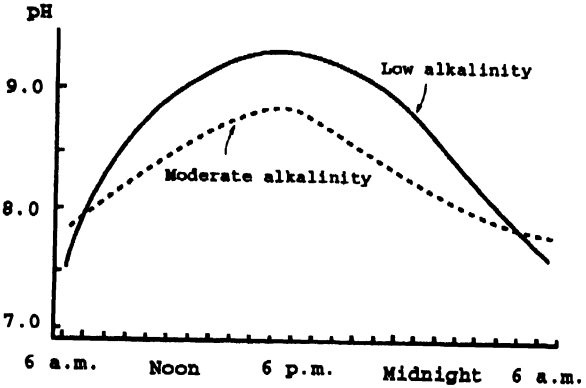

Figure 3. A demonstration of increased pH fluctuations in low alkalinity waters with limited buffering potential (Boyd 1990).

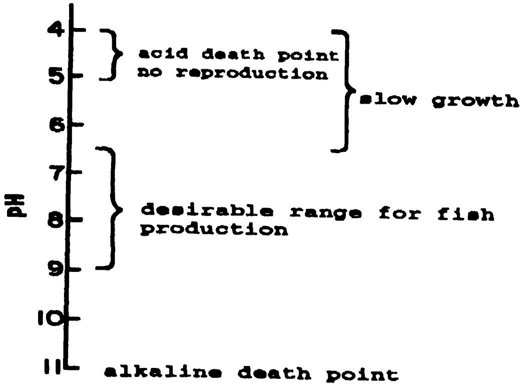

Figure 4. Illustration of how different pH levels affect fish growth (Boyd and Lichtkoppler 1979).

The quality of impounded waters is also affected by precipitation. Acid rain can lower the pH and total alkalinity of surface waters. The problem is compounded in areas having low total alkalinity. In the Northeastern United States and Canada, waters have been acidified by rain to pH levels below 5.0 as illustrated in Figure 5. Strongly acidified waters experience degradation at all trophic levels (Boyd 1990).

Impounded water also contains particulate matter. Suspended particles cause turbidity. Particles can be plankton, humic substances, or soil. Clay turbidity reduces photosynthesis by reducing light penetration and, in extreme cases, can adversely affect fish health. Plankton turbidity can improve fish production. Relative plankton abundance is calculated by measuring particulate organic matter. The relationship between plankton abundance and transparency as measured by Secchi disk visibility is demonstrated in Figure 6 (Boyd 1982).

Another important water quality variable is dissolved oxygen. Oxygen dissolved in water is used for respiration by fish and other aquatic organisms. The quantity of oxygen that can dissolve in water is a function of temperature and elevation. Oxygen is more soluble at lower temperatures and elevations. Tolerance to low levels of dissolved oxygen is species dependent. However, many fish exhibit slow growth when oxygen levels fall below 5 mg/liter for extended periods. The effects of varying concentrations of dissolved oxygen on fish are illustrated in Figure 7 (Boyd and Lichtkoppler 1979).

2.2 Biotic Factors

Biotic factors are frequently dependent variables which can be managed for fishery improvement. To enhance fish yield, it is important to understand how these factors affect aquatic production. Biotic factors include fertility of the environment; diversity of fish populations in terms of structure and function; foraging efficiency of predators in predator/prey systems; modifications of aquatic habitat; and population manipulation through planned fishing mortality.

2.2.1 Fertility

Fertility typically refers to the quantity of nutrients available. Higher fertility is usually equated with higher productivity. Primary productivity is the rate at which new organic matter is added through photosynthesis. In most small impoundments, photosynthesis is commonly limited by nutrients, so the greater the fertility, the higher the primary productivity. There is also a positive correlation between primary productivity and fish production. This is demonstrated in Figure 8, showing the relationship between sunfish production and plankton abundance measured as particulate organic matter (Boyd 1990).

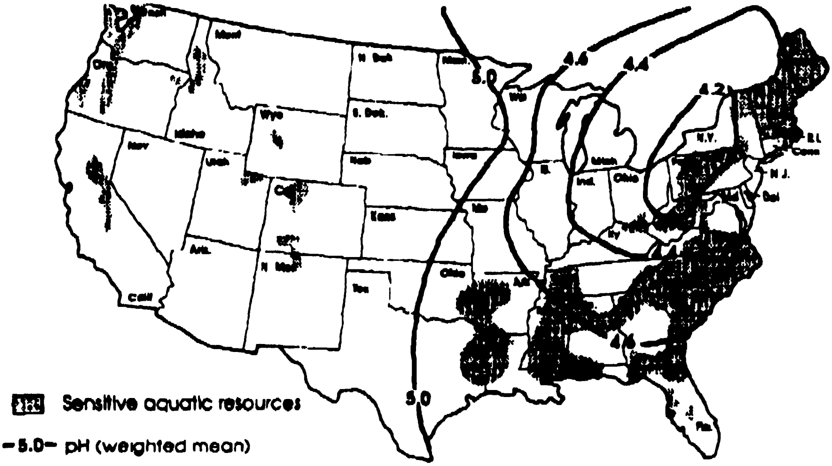

Figure 9. Conceptual model of the recruitment of quality largemouth bass into a system (Reynolds and Babb 1978).

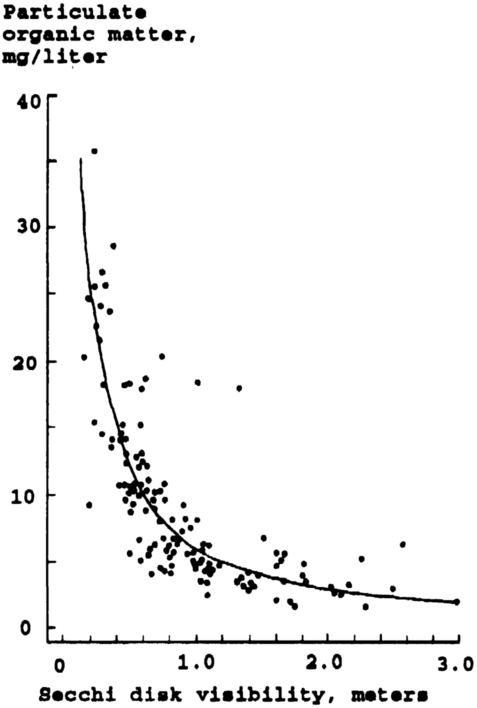

Figure 6. The relationship of visibility as measured by Secchi disk to plankton abundance as measured by particulate organic matter (Boyd and Lichtkoppler 1979).

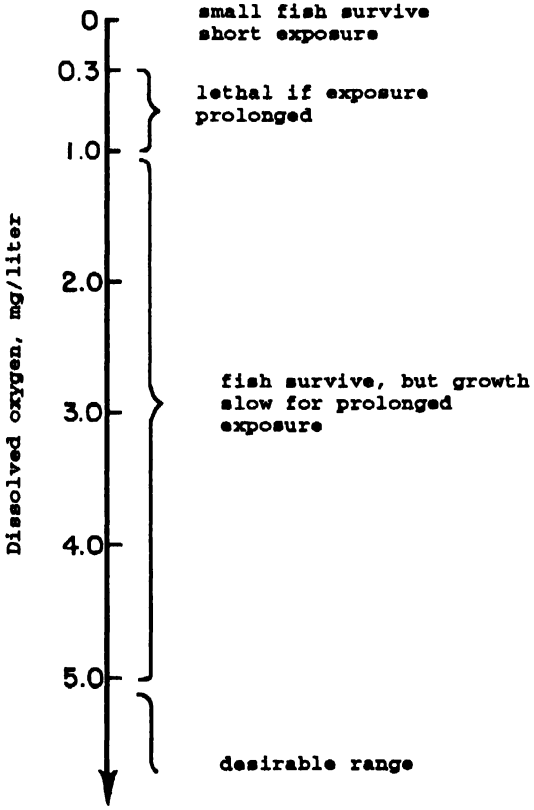
0
0.3
1.0
2.0
3.0
4.0
5.0
Dissolved oxygen, mg/liter
small fish survive short exposure
lethal if exposure prolonged
fish survive, but growth slow for prolonged exposure
desirable range

Figure 7. Affects of varying dissolved oxygen concentrations on fish growth (Boyd and Lichtkoppler 1979).

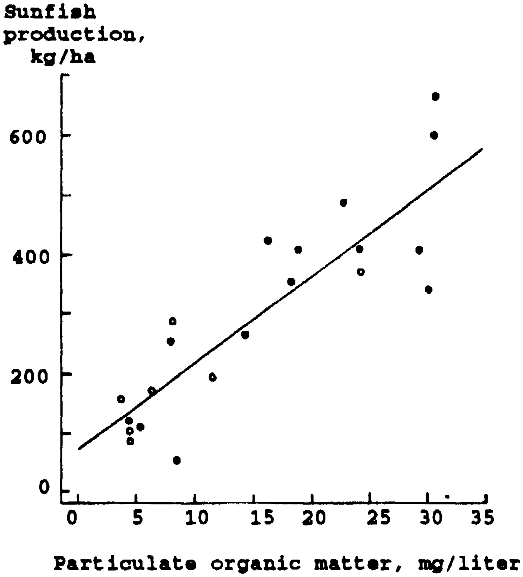

Figure 8. The relationship of fish production to plankton abundance measured as particulate organic matter (Boyd and Lichtkoppler 1979).

To a large extent, impoundment fertility is determined by the fertility of the locale. Nutrient-rich sites have more fertile waters. The least available nutrient limits productivity. When increased quantities of this nutrient are present, primary production increases until another less abundant nutrient becomes limiting. Phosphorous is frequently the first limiting factor in freshwater impoundments. Fertility may also be limited by nitrogen, carbon, sulfur, or other nutrients (Boyd 1990).

Impoundments in the southeastern United States are typically located in infertile areas. They are, therefore, often fertilized to enhance plankton abundance. Phosphate or phosphate and nitrogen combinations usually provide the best results. Liquid fertilizers are preferred since they are more readily available to plankton than granular forms. Table 2 shows fertilizers and application rates typically employed in small southern impoundments (Boyd 1976, Jensen 1985).

Table 2. Fertilizer application rates for maximum fish production (Jensen 1985).

Fertilizer Type	Fertilizer Grade	Fertilizer Application (kg/ha)
Liquid: ammoniated polyphosphate or ortho phosphate	9-32-0 10-34-0 11-37-0 13-38-0	10
Granular: fishpond fertilizer	20-20-5	40
Granular: diammonium phosphate	18-46-0	18
Granular: triple superphosphate (TSP) with ammonium nitrate (AN)	0-46-0 and 34-0-0	18 TSP and 24 AN

Fertilizers are less effective in soft waters with total alkalinity less than 20 mg/liter. Soft waters have inadequate carbon (usually in the form of carbon dioxide and bicarbonate) for good phytoplankton production. Fertilizer response, hence productivity, can often be enhanced by applying lime to low alkalinity impounded waters. The application of lime equivalent to 2,000 to 6,000 kg/ha calcium carbonate is generally sufficient to maintain total alkalinity above 20 mg/liter. Liming is not recommended in waters with total alkalinities greater than 20 mg/liter (Boyd and Lichtkoppler 1979, Boyd and Cuenco 1980, Jensen 1984, Pillai and Boyd 1985).

2.2.2 Species diversity

In general, the less diverse the fish community, the easier the system is to manage. A mono-culture system can be regulated to optimize conditions for the fish species present. As species are added, the complexity increases which may, or may not influence total fish yield.

In multi-species systems, fish can occupy different niches where competition is avoided or at least minimized. Species competition for space and food can occur if niches overlap for any life history stage. Predator/prey relationships for two-species systems such as largemouth bass and bluegill tend to minimize interspecific competition when the populations are in balance. Table 3 lists fishes stocked in small impoundments and their most common regions in North America.

Swingle (1950) referred to prey as forage fish and predators as carnivorous fish. He described the relationship between the two with the F/C ratio: the total weight of all forage fish (F) divided by the total weight of all carnivorous fish (C). The desirable F/C ratio in balanced populations was determined to be 3.0 to 6.0, based on draining largemouth bass-bluegill stocked farm ponds. Lower F/C values indicate overcrowding with predators. Higher F/C values reflect unbalanced populations with surplus prey species.

Swingle (1950) further described the relationships between different fish populations by the Y/C ratio and the A_T value. The Y/C ratio is the relationship between the total weight of prey small enough to be eaten by the average-size adult predator (Y) to the total weight of predators (C). Desirable values are 1.0 to 3.0. A_T describes the percent by weight of the total fish population composed of harvestable-size individuals. For balanced populations, the desirable value is 60 to 85 percent. These ratios provide guidelines for optimal conditions as described by the species contribution to total weight. The ratios and values do not provide direct information about the relative condition of members of these populations.

Biologists commonly use condition factors as indices of the relative quality of a fish population where the determination is based on the length/weight relationship of individual fish. There is a relationship between weight (W) and length (L) for a fish species or population (variously described by equations $W_c = aL^b$ or $W_c = CL^3$ where W_c is the calculated weight corresponding to a measured length).

The LeCren (1951) condition factor (K_n) is computed by dividing the observed weight (W_o) by a calculated weight (W_c) representing an average, or characteristic weight for a particular region. Adequate condition is represented by K_n values close to one.

Relative Weight (W_r) is another measure of condition. With this method, the weight of the fish is divided by the standard weight for its length and multiplied by 100, where the standard weight is computed from a least squares regression line through the seventy-fifth percentile weights in various length classes listed by Carlander (1977). Adequate W_r values for largemouth bass should be 95 to 100 (Anderson 1978).

Another indication of the quality of the fish population is the Proportional Stock Density (PSD). This represents the percent of stock-sized fish from a specific population that have attained a quality size. PSD is calculated by dividing the number of quality-size fish (Q) by the number of stock-size fish (S). A stock-size fish is one that has survived its first winter of life and is subject to the same natural mortality as adults in the population. Quality size, as total length, was established by Anderson (1978) as 30 cm and 15 cm for largemouth bass and bluegill, respectively. Proposed stock size was 20 cm and 7.6 cm for the two species, respectively. With

Table 3. Common and scientific names of fishes commonly stocked in small impoundments in North America and the regions where they frequently contribute to small impoundment fish communities. Fish are listed in order in which they appear in the text. Regions are those indicated in Table 1.

Common Name	Scientific Name	Regions
Largemouth Bass	*Micropterus salmoides*	Southeastern North Central Northwestern
Bluegill	*Lepomis macrochirus*	Southeastern North Central Northwestern
Channel Catfish	*Ictalurus punctatus*	Southeastern North Central Northwestern
Tilapia	*Tilapia aurea*	Southeastern
Common Carp	*Cyprinus carpio*	Southeastern North Central Northwestern
Golden Shiner	*Notemigonus crysoleucas*	Southeastern North Central
Yellow Perch	*Perca flavescens*	Southeastern North Central Northwestern
Gizzard Shad	*Dorosoma cepedianum*	Southeastern North Central
Threadfin Shad	*Dorosoma petenense*	Southeastern
White Crappie	*Pomoxis annularis*	Southeastern North Central Northwestern
Fathead Minnow	*Pimephales promelas*	Southeastern North Central
White Catfish	*Ictalurus catus*	Southeastern
Blue Catfish	*Ictalurus furcatus*	Southeastern
Striped Bass	*Morone* sp.	Southeastern North Central Northwestern
Walleye	*Stizostedion vitreum*	Southeastern North Central Northwestern
Rainbow Trout	*Salmo gairdneri*	Southeastern North Central Northwestern

Table 3. Continued		
Common Name	Scientific Name	Regions
Grass Carp	*Ctenopharyngodon idella*	Southeastern North Central Northwestern
Redear	*Lepomis microlophus*	Southeastern North Central Northwestern
Green Sunfish	*Lepomis cyanellus*	Southeastern North Central Northwestern
Black Crappie	*Pomoxis nigromaculatus*	Southeastern North Central Northwestern
Black Bullhead	*Ictalurus melas*	Southeastern North Central
Yellow Bullhead	*Ictalurus natalis*	Southeastern North Central
Warmouth	*Chaenobryttus gulosus*	Southeastern North Central
Short-nosed Gar	*Lepoidosteus platostomus*	Southeastern North Central
Bowfin	*Amia calva*	Southeastern North Central
Spotted Bass	*Micropterus punctulatus*	Southeastern
Smallmouth Bass	*Micropterus dolomieu*	Southeastern North Central Northwestern
Lake Chubsucker	*Erimyzon sucetta*	Southeastern
Brook Trout	*Salvelinus fontinalis*	Southeastern North Central Northwestern
Brown Trout	*Salmo trutta*	Southeastern North Central Northwestern
Cutthroat Trout	*Salmo clarki*	Northwestern
Pike	*Esox lucius*	Southeastern North Central Northwestern
White Sucker	*Catostomus commersonnii*	North Central
Brook Stickleback	*Culaea inconstans*	North Central

these parameters, desirable values for PSD were 40 to 60 percent for largemouth bass and 20 to 40 percent for bluegill.

Figure 9 illustrates a conceptual model for recruitment of bass into a system as a function of size. When systems are in "balance," rates of recruitment are adequate to sustain reasonable harvests. Quality production is an indication of systems in balance. Figure 10 uses PSD to indicate systems in balance relative to systems functioning outside the balanced range.

2.2.3 Foraging efficiency

In predator/prey systems such as the largemouth bass-bluegill combination frequently used in small impoundments, the forage or predation efficiency of the predator is important to maintain balanced populations. Largemouth bass forage predominately by sight, being most effective under low light conditions. Feeding success declines as the density of visual barriers increases (Arnoldi et al. 1990).

When aquatic weeds occupy more than 20 percent of the water area, the foraging efficiency of largemouth bass can decrease (Anderson 1983, IDC 1992). Aquatic weeds also compete with beneficial plankton for nutrients, interfere with harvest, and can contribute to oxygen depletions (Dendy 1963). Aquatic weed growth is encouraged by shallow water. To avoid excessive weed growth, pond banks should slope rapidly (2:1 or 3:1 ratio) to a depth of 75 cm or more (Masser 1992).

Largemouth bass require bluegill prey that are roughly 15 percent of bass total length to express a relative condition of 1 or 100 percent; those fish feeding routinely on smaller or larger prey characteristically expressed levels of condition less than, or greater than, 100 percent, respectively (Davies 1987). Foraging efficiency in terms of the availability of appropriate size prey is probably important for large keystone predators to maintain acceptable growth rates.

Although largemouth bass do not readily consume supplemental fish feeds, feed consumed by bluegills will be reflected by better condition, higher fecundity, and more prey available for bass. Feeding also contributes to harvest of robust bluegill, channel catfish, and trout. When a feeding regimen is incorporated into an impoundment management scheme, average size of harvestable fish and total production can double (Masser 1992).

Feed with 25 percent protein is adequate for growth. This can be fed during warmer months (water temperature $\geq$ 15° C) at a daily rate not exceeding 10 kg/ha. Winter feeding (water temperature < 15° C) is not usually necessary but provides some added growth. Winter daily feeding rates should not exceed 3 kg/ha. Since feeding increases impoundment fertility, regular feeding may make it unnecessary to fertilize the pond water.

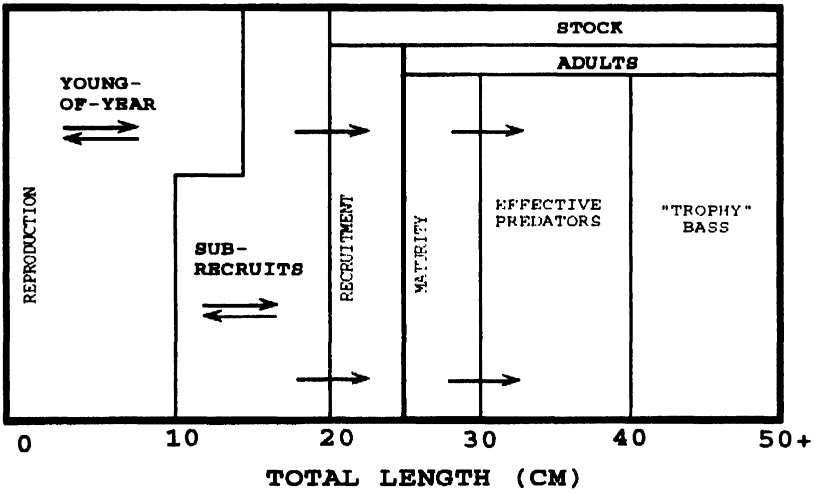

Figure 9. Conceptual model of the recruitment of quality largemouth bass into a system (Reynolds and Babb 1978).

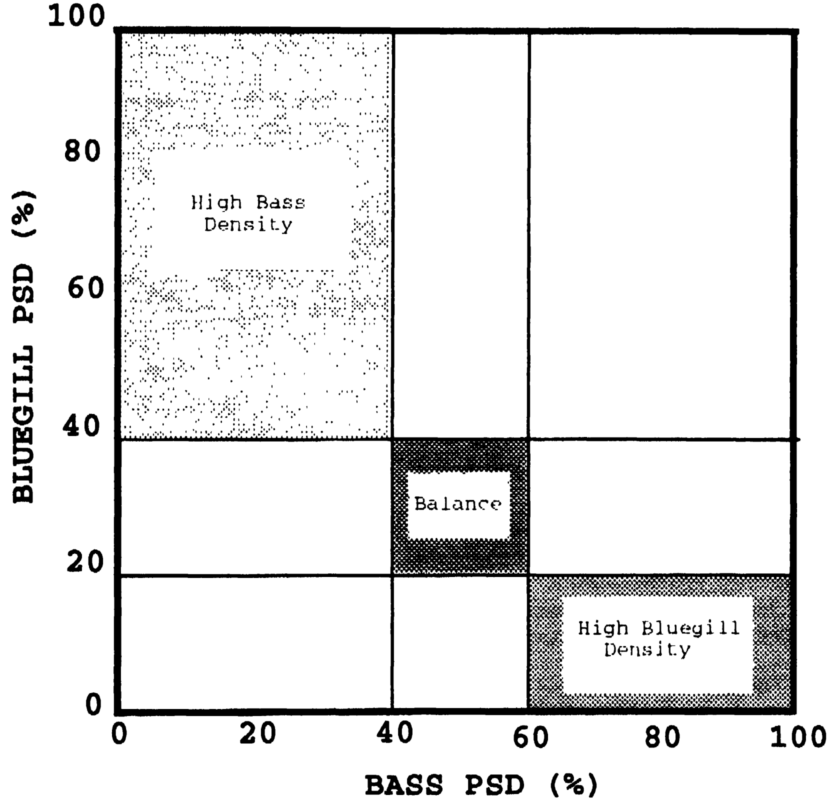

Figure 10. Varying proportional stock densities (PSD) for bluegill and largemouth bass indicating systems in and out of balance.

2.2.4 Fishing mortality

Production and yield in fish populations are influenced by rates of growth, reproduction, and mortality within a population. Rates in turn are affected by species density and diversity which influences levels of competition. Ultimately, for a given latitude, the productivity of the system determines allowable harvest rates. Schlesinger and Regier (1982) calculated isolines showing predicted maximum sustainable yields for optimum conditions across the North American continent; yields varied from 1 kg/ha/yr in Northern Canada to approximately 100 kg/ha/yr in southern Mexico and reflect latitudinal differences due to temperature.

Within a region, acceptable rates of exploitation usually depend upon the functional role that a particular species plays in the system. For example, largemouth bass as the keystone predator in maintaining a dynamic state within prey populations is a consideration in many warm water sport fisheries. In one system, an acceptable rate of exploitation for a largemouth bass population could be 40 percent, while in other systems no bass should be harvested. The former system is often characterized by low species diversity, and high bass recruitment to age one; the latter systems are usually characterized by having high species diversity where few bass recruit to the adult population. Fertility levels can affect the level of competition thereby influencing the availability of appropriate-sized prey, and subsequently affecting bass recruitment.

The influence of fertility and largemouth bass recruitment on surplus production is summarized in Figure 11 (Davies 1987). Davies determined harvest rates based on the number of largemouth bass that could be removed while maintaining a dynamic state within prey populations for the Southeastern Region. In some systems, i.e., the lower right quadrant in Figure 11, high fertility and high species diversity may dampen recruitment of bass in most years so that very little, if any, surplus is available. Factors affecting largemouth bass recruitment are direct interspecific competition for food by prey species that spawn before bass in the spring (eg., golden shiner; yellow perch), and indirect competition by adult prey species that utilize larger zooplankton (eg., gizzard and threadfin shad).

The structure of fish populations can be influenced by length limits to restrict harvests of certain size fish (Novinger 1984). For length limits to be effective, fishing mortality must be high relative to the rates of production and natural mortality in the fish population. For example, "slot-limits" are often imposed on bass populations when recruitment of bass to age one is satisfactory, and there is insufficient prey of the appropriate size to allow the majority of bass to grow quickly to a quality size. High minimum size limits are usually imposed on populations where recruitment is low, and bass of all sizes are needed to prey on overly abundant prey populations, and provide larger bass to maintain acceptable catch rates in the sport fishery.

Maximum rates of exploitation, especially on predator populations, are a function of the time period over which exploitation occurs, and how quickly fish are recruited into the harvestable size range. Higher rates of exploitation are possible when fish are harvested, and have the capacity to grow, throughout the year.

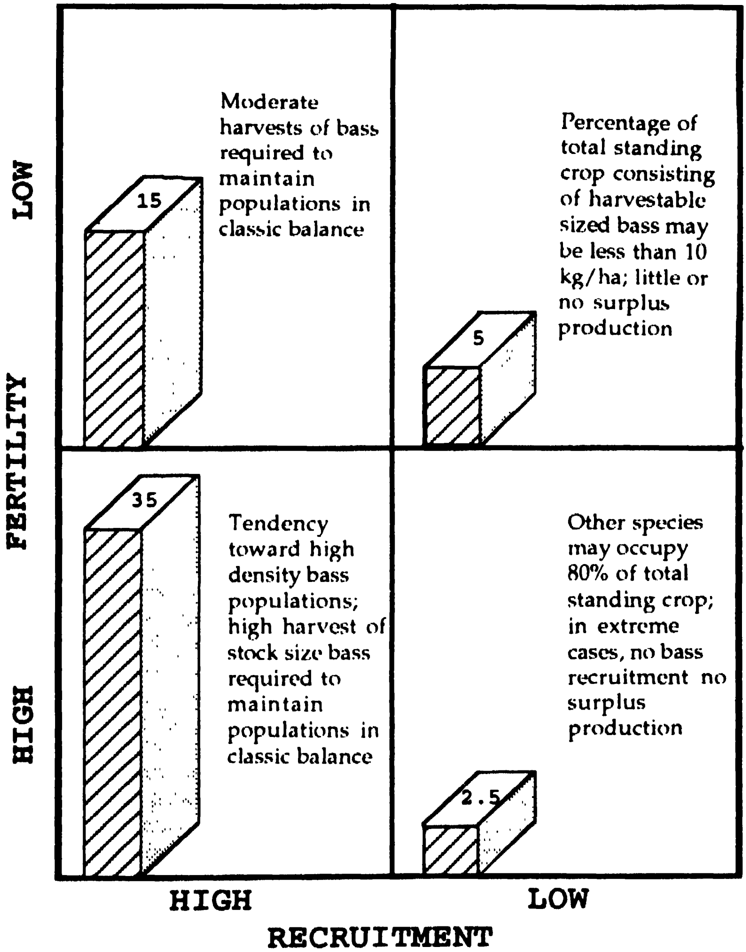
LOW
FERTILITY
HIGH
15
Moderate harvests of bass required to maintain populations in classic balance
5
Percentage of total standing crop consisting of harvestable sized bass may be less than 10 kg/ha; little or no surplus production
35
Tendency toward high density bass populations; high harvest of stock size bass required to maintain populations in classic balance
2.5
Other species may occupy 80% of total standing crop; in extreme cases, no bass recruitment no surplus production
HIGH
LOW
RECRUITMENT

Figure 11. The relationship of fertility and recruitment as they affect largemouth bass harvest, indicated as kg/ha available for harvest.

3. MANAGEMENT STRATEGIES

3.1 Diversity of North American Setting

North America, excluding Mexico, stretches from the Tropic of Cancer to 70° North latitude, and from 50° to 170° West longitude. Elevations range from below sea level to more than 6,000 m. Temperatures vary from below - 50° C to above 42° C and precipitation from less than 100 mm to more than 2,500 mm.

North American waters have a chemical composition that changes with geology and climate. In areas where soil minerals are relatively insoluble or rainfall is abundant, concentrations of dissolved ions are low, with total dissolved solids often less than 20 mg/l. Dry regions with soluble minerals may have concentrations of total dissolved solids exceeding 2,000 mg/l (Boyd 1990).

3.2 Case Studies

The following case studies elaborate small impoundment management in the Southeastern, North Central, and Northwestern regions of North America. Regions are delineated by climate and species commonly representing the fishery. States within each region are indicated in Table 1. Canadian impoundments are included in the Northwestern region.

3.2.1 Impoundment management in Southeastern region

The Southeastern region of the United States possesses more small impoundments than any other area. The region is characterized by a climate ranging from hot and humid with mild winters to hot and arid with severe winters.

Alabama typifies hot and humid conditions in the Southeastern region. Annual rainfall averages 1,500 mm (Boyd 1982). Winter water temperatures range from 4 to 13° C (Swingle 1952). The state has approximately 50,000 small, private impoundments covering more than 54,000 ha (Masser 1992).

Swingle (1967) defined warmwater impoundments as those where the water temperature of the upper 30 cm of water exceeds 24° C during the hottest season. He recommended stocking fertilized warm water impoundments with largemouth bass-bluegill combinations. He proposed stocking 2,500 fingerling bluegill per hectare in October and November such that they would spawn the following April and May. Largemouth bass fingerlings are stocked in May and June, when abundant bluegill forage is available. In fertilized waters, recommended largemouth bass densities are 200 to 250 per hectare.

Table 4. Stocking recommendations for Alabama impoundments (Masser 1992).

Species	Stocking Fertilized Impoundments (number/ha)	Stocking Unfertilized Impoundments (number/ha)
Bluegill	2,500	1,250
Bluegill/redear combination	2,000 bluegill and 500 redear	1,000 bluegill and 250 redear
Largemouth bass	250	125
Channel catfish	125 to 250	60

If bluegill stocking is delayed and ample forage is not available for young bass, 2,500 fathead minnows can be stocked per hectare in February or March. Fathead minnows will spawn in February and provide forage for young-of-year bass. As a "disappearing species," the minnows will ultimately be consumed by the expanding largemouth bass population. Fertilized warm water impoundments managed in this way can maintain an annual harvest of approximately 150 to 170 kg/ha, including not more than 30 kg of largemouth bass.

To the original largemouth bass-bluegill combination, additional species have been added including: channel catfish, white catfish, blue catfish, threadfin shad, gizzard shad, striped bass hybrids, walleye, rainbow trout, and grass carp. Largemouth bass, bluegill, and redear remain the most important species for impoundment management (Reeves and Harders 1990). Table 4 represents current Alabama stocking recommendations for small impoundments.

Although as much as 25 percent of the recreational fishing in Alabama takes place in small impoundments, most ponds are not intensively managed. Management includes proper fertilizing and stocking (Masser 1992). Since fertility is related to plankton abundance and Secchi disk visibility (Figure 6), measuring water transparency can guide managers attempting to improve production (see Table 5).

Swingle (1956) determined that the relative balance among fish populations in an impoundment could be estimated by seine analysis. He proposed seining a portion of the shoreline with 4.5 m-long net, 0.9 m deep, with 0.32 cm mesh in May or June, after the bluegill have begun spawning. The size and species composition of the catch is an indication of the impoundment's balance. These techniques have been expanded for use by the Alabama Department of Conservation (White 1990). Typical seine data and corresponding angler catch data are presented in Table 6.

Table 5. Secchi disk visibility and corresponding management recommendations to maintain acceptable fertility of impounded water (Masser 1992).

Secchi Disk Visibility (cm)	Management Recommendation
Greater than 60	fertilize
45 to 60	good bloom -- do nothing
30 to 45	dense bloom -- watch closely
30 or less	bloom too dense -- determine source and be prepared to aerate at night
15 or less	oxygen depletion imminent

Texas represents semi-arid conditions in the Southeast region. The state has a varied climate with average annual rainfall from less than 400 mm to more than 1,000 mm and air temperatures from below -10° C to 40° C. Texas has more small impoundments than any other state in the United States. More than 20 percent of fishing trips in Texas are made to small impoundments. However, most of these waters are not managed (AFS 1985).

Small impoundments in Texas are divided among three geographic zones: Zone I, with more than 1,000 mm of precipitation annually and acid soils, occupying the eastern corner of the state; Zone II, with 750 to 1,000 mm of annual precipitation, prairie and savannah in the east-center of the state with less acid soils; and Zone III, with less than 750 mm of annual precipitation, in high plains and mountains, with more alkaline soils, occupying the western half of the state. Ponds in Zone I remain full throughout the year while those in Zone III experience radical drawdowns during the driest months. Drawdowns concentrate fish and pose greater threats of oxygen depletions. Ponds in Zone III are often up to five meters deep (AFS 1986).

Stocking recommendations by zone for unfertilized waters are described in Table 7. These apply to water areas of 0.4 to 2 ha. Impoundments less than 0.4 ha are stocked only with channel catfish. Stock-size fingerlings for all species have a total length of 3 to 8 cm. Densities can be doubled in ponds receiving an annual fertilization program. Muddy waters or catfish impoundments receiving feed more than three times a week are not fertilized. It is strongly recommended that crappie, hybrid sunfish, carp, bullheads, green sunfish, or flathead catfish not be stocked in impoundments without consulting a fisheries biologist (AFS 1986).

Table 6. Evaluation of balance of largemouth bass-bluegill populations using a 5 m seine and catch data (Masser 1992).

Type of Fish Caught	Conclusion	Recommendation
Seine data: small and intermediate bluegill and young-of-year largemouth bass Angler catch data: bass and bluegill of various sizes	fish population in balance	no additional management necessary
Seine data: many intermediate bluegill and few or no young-of-year bass Angler catch data: few harvestable size bluegill; few large bass	bluegill-crowded	remove intermediate bluegill by shore line rotenone in fall or stock 50 to 75 adult (> 30 cm) bass per hectare
Seine data: few intermediate bluegill; many recently hatched bluegill Angler catch data: bass numerous but small and thin; bluegill few but large and robust	bass-crowded	remove 125 to 200 (35 kg) bass per hectare and stock 500, 10 to 12 cm bluegill per hectare
Seine data: unwanted species, no recent bluegill hatch, few intermediate bluegill Angler catch data: few harvestable size bluegill and unwanted species (crappie, bullhead, green sunfish, shiners, etc.)	fish population dominated by unwanted species	rotenone and start over

Table 7. Stocking recommendations for Texas impoundments, by climatic zone (AFS 1986).

	Zone I	Zone II	Zone III
Large-mouth bass stocking (no/ha)	125	125	125
Forage stocking (no/ha)	625 bluegill and 625 redear	1,250 bluegill	1,250 bluegill and 1,250 golden shiners
Channel catfish stocking (no/ha)	250	250	250
Optional species and densities	threadfin shad (500/ha), golden shiners (1,250/ha), or fathead minnows(1,250/ha)	redear (625/ha), threadfin shad (500/ha), golden shiners (1,250/ha), fathead minnows (1,250/ha)	redear (625/ha), threadfin shad (500/ha), fathead minnows (1,250/ha)

In areas with extreme water drawdown, bluegills alone do not provide adequate prey for largemouth bass. Crowding and clear water combine to increase bass foraging efficiency and additional species are often stocked to ensure sufficient prey. This is especially common in Zone III, where golden shiners are added to the fish population. Other supplemental forage fish include fathead minnows and threadfin shad (AFS 1986).

3.2.2 Impoundment management in North Central region

Illinois, in North Central United States, is representative of cooler climates with most ponds freezing over during winter months. For much of the state, average annual rainfall is less than 1,000 mm with seasonal air temperatures fluctuations from below -10° C to above 30° C. The state reports 84,603 small impoundments less than 2.5 ha,with a total water surface area of more than 24,000 ha, with 400 new impoundments annually (IDC 1992).

Illinois impoundments have been the focus of considerable attention through the work of Bennett (1945, 1951, 1952, 1962). In the 1940s, Bennett attributed poor fish yields to inappropriate fish communities. After studying 22 Illinois impoundments, he concluded that only six of 42 species were useful: largemouth bass; white crappie; black crappie; black bullhead; yellow bullhead; and bluegill. Bennett noted that a largemouth bass-bluegill combination was advantageous due to acceptance by fishermen and compatibility of the two species. However, bluegill tended to overpopulate impoundments because in Illinois, they mature one year before largemouth bass, and alternative bass prey, such as crawfish, reduce predation on bluegill.

Bennett proposed species combinations but not specific stocking rates. He maintained that optimum predator/prey ratios for largemouth bass-bluegill impoundments could not be applied in a general fashion since bass were omnivorous, not depending entirely upon bluegill as prey. He preferred to recommend a range of possible population structures (Wenger 1972).

Fertilization of impoundments was not recommended since the additional yield did not compensate for the cost of the fertilizer. Moreover, fertilization tended to create nuisance algal blooms. Depending upon their natural fertility, Illinois impoundments supported standing crops of 71 to 1,145 kg/ha (Bennett 1952).

Bennett's work provided a foundation for current impoundment management guidelines recommended by the Illinois Department of Conservation (IDC 1992). Recommendations include stocking largemouth bass, channel catfish, and bluegill. When over reproduction of bluegills is a consideration, a 70/30 bluegill/redear combination may be used. Crappies, although popular, are not recommended since they quickly overpopulate the impoundment.

Table 8 summarizes management practices for Illinois impoundments. Fingerlings of all species are stocked at a total length of 2.5 to 7.5 cm. Five-centimeter fathead minnows may be added as a disappearing prey to provide a quality food source for other young fish. In cooler areas, it is possible to stock 25 cm rainbow trout in October at 250 to 1,250 per hectare. These can be harvested through May the following year when temperatures become too high for these fish.

In Illinois, bluegill populations are self-sustaining when stocked as indicated in Table 8. Recruitment by channel catfish will be poor and 20 cm individuals should periodically be restocked to maintain constant numbers. If largemouth bass become crowded (high density), Bennett recommended adding several hundred adult bluegill per hectare. In bluegill-crowded situations, 20 to 25 cm largemouth bass should be added at a rate of 60 to 250 per hectare.

Table 8. Stocking recommendations for Illinois based on the alkalinity of the impounded waters (IDC 1992).

Item	Good Fertility	Average Fertility	Fair Fertility
Alkalinity	> 100 ppm	50 to 100 ppm	< 50 ppm
Number largemouth bass stocked per hectare	150 to 250	125 to 225	100 to 200
Number channel catfish stocked per hectare	150 to 250	125 to 225	100 to 200
Number bluegill stocked per hectare	1,250 to 2,500	1,000 to 2,000	750 to 1,750
Number bluegill: bluegill/redear combination	1,225 to 1,750	875 to 1,225	612 to 875
Number redear: bluegill/redear combination	525 to 750	375 to 525	262 to 375
Bass carrying capacity (kg/ha)	100	50	25
Bluegill and/or redear carrying capacity (kg/ha)	400	200	75
First year angler bass harvest	none	none	none
First year angler bluegill harvest	none	none	none
Second year angler bass harvest	catch and release	catch and release	catch and release
Second year angler bluegill harvest (per hectare)	1,600 fish* or 160 kg	800 fish* or 80 kg	300 fish* or 30 kg
Third year angler bass harvest (per hectare)	100 fish or 40 kg	50 fish or 20 kg	25 fish or 10 kg
Third year angler bluegill harvest (per hectare)	1,600 fish* or 160 kg	800 fish* or 80 kg	300 fish* or 30 kg
Succeeding years angler bass harvest	100 fish** or 40 kg	50 fish** or 20 kg	25 fish** or 10 kg
Succeeding years angler bluegill harvest	1,600 fish* or 160 kg	800 fish* or 80 kg	300 fish* or 30 kg

* Fifteen centimeters and longer

** After quota is reached, all bass over 45 centimeters can be harvested

Table 9. Largemouth bass, bluegill, and channel catfish stocking recommendations for Kansas. Densities are per hectare, fish are stocked as fingerlings unless otherwise specified (Gablehouse et al. 1982).

Option	Year 1	Year 2	Year 3	Year 4
All-purpose	3 kg fathead minnows, 1,250 bluegill, 250 catfish	250 bass	10 pike	Panfish
3 kg fathead minnows, 1,250 bluegill, 250 catfish	250 bass		50 black crappie or 50 black bullhead & 10 pike	Big bass
3 kg fathead minnows, 1,250 bluegills, 250 catfish	250 bass	250 walleye	50 gizzard shad adults	Catfish only
3 kg fathead minnows, 250 to 500 catfish				

Management practices, as outlined in Table 8, do not include supplemental feeding of fish. Feeding is discouraged since there is a tendency to overfeed, leading to possible oxygen depletions and fish mortality. If fish are fed, an initial rate of 2 kg/ha/day is recommended, with a gradual increase to a maximum rate of 10 kg/ha/day.

Stocking recommendations for another North Central state, Kansas, are presented in Table 9. The proposed program involves sequential stocking of various species over a period of four years. As an alternative to these recommendations, the state also proposes stocking adult fish.

In this scenario, largemouth bass, bluegill, and channel catfish numbers are reduced by half and companion species (northern pike, black crappie, black bullhead, and gizzard shad) are stocked in year three rather than year four (Gablehouse et al. 1982).

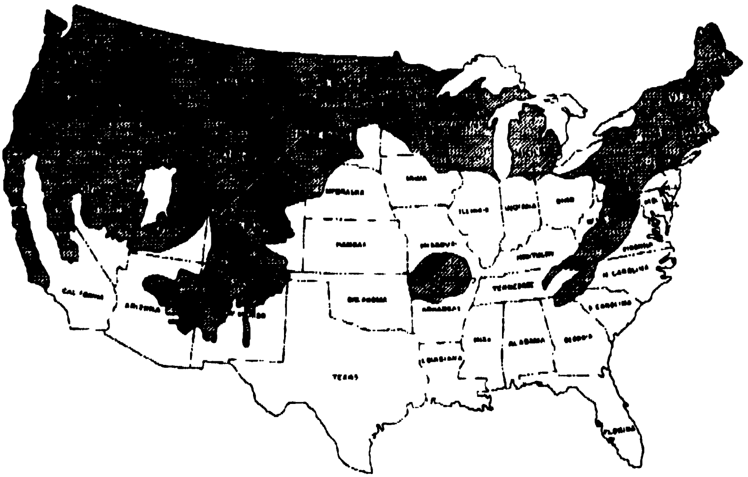

Figure 12. Regions of the United States with climatic conditions suitable for growing trout (Scheffer and Marriage 1975). Suitable regions are indicated by the shaded area of the map.

3.2.3 Impoundment management in Northwestern region

The Northwestern region offers both warm water and cold water habitats. Humid areas on the Pacific coast receive more than 1,000 mm of annual precipitation while the central plateau (Great Basin) has less than 300 mm annually. Air temperatures are equally variable with valleys of Oregon having temperatures between 1° and 27° C while temperatures in the region can fall below -40° C. Impoundments are frequently delineated by elevation, with warm water impoundments located below 1,000 m. As representative of the region, Idaho anglers prefer fishing for coldwater species by a ratio of three to one. The most popular coldwater species is the rainbow trout. Warmwater fishing is, however, rapidly gaining popularity, with bass the preferred species (IFG 1990).

Impoundments in the West above 1,500 m are often stocked with trout. Trout can tolerate water temperatures ranging from 1 to 24° C, but do best at 10 to 18°

C (Marriage et al. 1971). Trout require at least 5 ppm dissolved oxygen and do best in water with total dissolved solids of 50 to 250 ppm . Figure 12 indicates those areas of the United States which are suitable for raising trout (Scheffer and Marriage 1975).

Trout species frequently introduced include rainbow, brook, brown, and cutthroat. Rainbow are most common, brook trout are popular in some eastern areas, brown trout grow larger but are more cannibalistic, and cutthroat are seldom used and not readily available from hatcheries. For all species, 5 to 10 cm fingerlings are stocked at 1,250 to 1,500 per hectare. At these rates, 18 to 20 cm fish can be harvested after one year. At half these stocking densities, a spring stocking will provide 25 cm fish by fall. With no natural reproduction, impoundments are restocked after the second year to ensure an adequate standing stock. In waters with average fertility, natural food available will support approximately 100 kg of trout/ha. This carrying capacity can be increased 10 to 20 times by feeding a commercial feed (Marriage et al. 1971).

Feeding practices depend upon water temperature and the size of the fish. In commercial production, juvenile and adult fish are fed a ration with 35 to 40 percent dietary protein. Feed is given at two to five percent standing stock per day (i.e. 2-5 kg feed/100 kg fish). Higher feeding rates are appropriate for smaller fish and warmer temperatures (Lovell 1989).

On the Canadian prairies in Manitoba and Saskatchewan, small alkaline impoundments called "pot holes" are used to raise rainbow trout. These impoundments are stocked in April and harvested in October. Survival to harvest is about 70 percent, with harvested fish averaging 28 cm in length. Feeding is not required since these waters have abundant populations of the crustacean *Gammarus lacustris*. The waters freeze solid in winter, thereby ensuring no wild fish present in the impoundments at the time of stocking. It has been estimated that the Canadian pot holes can produce 4.5 million trout a year (Russey n.d., Bardach et al. 1972).

Latitudinal effects have prompted some fisheries biologists to recommend that bluegill not be stocked with largemouth bass in northern regions. Modde (1980) found that 14 of 20 Northern states above 40° North Latitude had specific stocking policies for warm water impoundments. Of these, five states recommended largemouth bass-bluegill for warm water impoundments while nine proposed alternatives to the largemouth bass-bluegill combination. The most common alternatives were bass only and bass with golden shiners.

Modde (1980) suggested alternative stocking strategies resulted from a slower growth of largemouth bass and bluegill in northern latitudes with harvestable fish not available until the third year after stocking. Other contributing factors included a greater interest in northern areas on largemouth bass rather than panfish angling, the deeper northern impoundments (to avoid winter-kill) were more difficult to manage, and the relatively low fishing pressure in northern impoundments encouraged bluegill overpopulation.

Willis and Guy (1991) compared results of stocking strategies popular in southern and eastern regions with results obtained in South Dakota (45° North Latitude). In addition to largemouth bass-bluegill combinations, they examined largemouth bass-yellow perch and largemouth bass-black bullhead combinations. They concluded that any of these combinations were suitable for impoundments less than 40 ha and deep enough to avoid winterkill. However, with slower growth in cooler climates, management for large panfish sacrifices quality largemouth bass while management for large largemouth bass produces small panfish.

Table 10. Summary of recommendations for fishery intensification in small impoundments based on species that function similar to largemouth bass-bluegill under temperate conditions.

Item	Low Management Level	Medium Management Level	High Management Level
Carrying Capacity	100 kg/ha	200 kg/ha	300 kg/ha
Secchi Disk Visibility	> 2 m	1 to 2 m	< 1 m
Lime Input (Alkalinity)	none	Lime to alkalinity > 20 ppm $CaCO_3$	Lime to alkalinity > 20 ppm $CaCO_3$
Fertilizer Input (10-34-0)	none	5 kg/ha when water temperature > 15.5° C	10 kg/ha when water temperature > 15.5° C
Prey Stocking Density	800 fish/ha	1,600 fish/ha	2,400 fish/ha
Predator Stocking Density	80 fish/ha	160 fish/ha	240 fish/ha
Sustained Prey Yield	42 kg/ha	84 kg/ha	126 kg/ha
Sustained Predator Yield	8 kg/ha	16 kg/ha	24 kg/ha

Davies and Rwangano (1991) assessed small impoundments in Oregon. The state has 60,400 hectares of small water area, mainly located in the Willamette Valley (75 to 170 meters), receiving 1,000 to 1,500 mm of annual rainfall. The authors surveyed 27 farm pond fish populations. They found largemouth bass and bluegill populations functioning at relatively low fertility (Secchi disc visibility in excess of 2 meters); vegetative cover apparently influenced how fish populations were structured. Largemouth bass in ponds with macrophytes covering less than 15 percent of the surface were in relatively poor condition, while bluegills were few, but large. Ponds with vegetative cover exceeding 15 percent during July-August had largemouth bass with relative condition often exceeding 100, and abundant small adult bluegills.

The inverse relationship between largemouth bass condition and bluegill size confirms the functional role bass play in maintaining a quality panfish fishery. Largemouth bass were apparently able to forage effectively on bluegill in ponds where vegetative cover did not exceed 15 percent during mid-summer. The authors suggest that harvesting small bass from these ponds would be appropriate, as well as increasing total standing stock through a fertilization program. In ponds where vegetation covered more than 15 percent of the surface, few harvestable size bluegill were present. The authors suggest reducing vegetative cover to the extent that largemouth bass of all sizes are able to feed more efficiently on bluegills.

3.3 Synthesis of Management Strategies

In the above case studies we discussed small impoundment management in three regions encompassing 31 states of the United States and two provinces of Canada. The success of efforts to improve small impoundment fisheries is demonstrated by increasing sport fishing pressure on these water bodies as anglers obtain increasing catch for fishing effort. More states are interested in improving or developing small impoundment sport fisheries, as existing resources are no longer able to accommodate angler demand.

Largemouth bass-bluegill systems are gaining popularity in areas where quality fishing was once limited to white-water trout streams. However, the success of small impoundment fisheries is more a result of principles employed in effectively managing predator/prey relationships than of the species employed. Equally successful small impoundment fisheries have been established using chichlid species in the role of predator and prey (Davies 1972). Modifications of systems identified by Swingle and Bennett are necessary if a small impoundment fishery is to be managed under conditions different than those of temperate North America. Growing seasons, desirable harvest sizes, and fishing pressure vary, but principles employed in North America are applicable to other regions of the world.

The role of predation in maintaining a dynamic state within fish populations in impounded waters is emphasized throughout our discussion. Swingle felt that stocking appropriate numbers of fingerlings in new or recently renovated ponds would enhance the probability of fish populations coming into a "balanced" state one year after stocking, or when the populations reached carrying capacity. Thereafter, Swingle emphasized the importance of predation to maintain appropriate biomass ratios within populations. In larger, more diverse aquatic communities, competition may limit recruitment of predators to the extent that predation may have little effect on the structure of other fish populations.

How fish perceive the availability of appropriate size prey determines their feeding efficiency. The presence of aquatic vegetation providing "safe havens" for prey species can affect how efficiently some predators feed, and therefore what portion of the population can be considered surplus. Prey species, on the other hand, may be restricted to feeding along the margins of ponds because of a high density of predators.

Across a wide range of latitudes, aquatic vegetation covering less than 15 to 20 percent of the ponds' surface area at the end of the growing season does not seriously interfere with predator/prey relationships. Some vegetation may even be desirable, by allowing prey species to persist in adequate numbers when low fishing mortality fails to remove "surplus" predators. Fitting harvest strategies to surplus production in both predator and prey species is the key to maintaining balanced fish populations.

Managing water quality through liming and fertilization to enhance productivity should only be a consideration when natural production is not satisfactory. The relatively soft waters of Western Oregon and some regions in the Southeast, for example, benefit from liming (carbonates) and fertilization (mainly phosphates). The increase in production, often by a factor of 2 or 3, may justify the additional costs. In those areas where natural soil fertility and pH support standing stocks of warm water fishes in excess of 250 kg/ha, fertilization is usually not recommended. Across a wide rage of latitudes, feeding at the recommended rates can dramatically increase production. Water quality is adversely affected when feeding rates exceed 10 kg/ha/day.

Proper management of low-diversity predator/prey populations and enhancement of natural productivity leads to the development of aquatic systems where energy is focused on growth. Table 10 summarizes the management recommendations for fishery intensification in small water bodies. These general practices can be fine-tuned to meet a wide range of management situations. Yields indicated for predator and prey species represent averages for temperate climates.

3.4 Economic Considerations

Economic considerations involve cost-benefits of small impoundments. Small impoundment fisheries have an economic value that is often hard to quantify, while management costs are readily apparent. Fisher and Grambsch (1991) discussed methods to evaluate warm water recreational fisheries. They concluded that values are composed of cash flows into the fisheries sector as a result of recreational fishing plus the net economic value (the difference between the total value and expenditures). The latter figure deals with the level of satisfaction obtained by fishermen. Such nonmarket values are difficult to measure, but if excluded from an evaluation, will result in a lower appraisal of the fishery than warranted. Efforts are underway to better assess nonmarket values associated with fisheries to better equate them with market goods when allocating resources.

Although it is difficult to appraise benefits from a multipurpose impoundment, costs are readily apparent to the manager. Expenses include initial investment in construction and management costs. Total construction costs, including site preparation, excavation, standpipe and spillway, and stabilizing margins, but excluding land purchases, average about $5,000 per hectare. Construction costs at more difficult sites can be more than double this amount.

Management costs include purchase of fish stock, routine maintenance of banks and waterways, liming, fertilization, and supplemental feeding. In the United States, cost of young-of-year largemouth bass and bluegill to stock one hectare is $340; lime, granular fertilizer, and feed cost approximately $0.015, 0.15, and 0.33 per kilogram, respectively. Liquid fertilizer costs roughly $0.50 per liter. Prices are quoted in 1992 United States dollars.

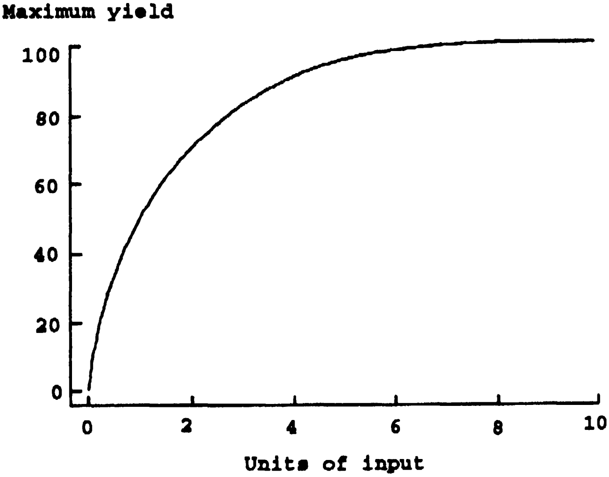

Figure 13. The response of the yields to increasing levels of input (Boyd 1990).

As with all production systems, yield increases resulting from increasing inputs are subject to diminishing returns as illustrated in Figure 13. At a certain input level, there is no longer a corresponding increase in output. Economically, the input level that maximizes profit is when the value of increased output caused by an additional unit of input is equal to the cost of the input. Therefore, to justify fertilizing or feeding, the value of additional fish yield should be equal to or greater than the cost of the fertilizer or feed. For example, to warrant increasing feeding rates from 2 kg/ha to 10 kg/ha/day, the value of fish yield would have to increase by $79 per hectare per growing season to cover the cost of additional feed.

3.5 Institutional Considerations

Institutional considerations relate to how fishery management recommendations are provided to the target population. In most cases, chief clients are residents of rural areas with adequate land and water resources. Although Swingle's initial orientation was to provide a ready source of high quality, low-cost animal protein to rural farm families, today small-scale farming has declined as a primary source of family income. Rural inhabitants are frequently involved in non-agricultural careers, and the pond owner is now more likely to have business than farming as a principal occupation.

The degree to which fishery management recommendations are accepted depends in part upon the perceptions of the pond owner. Private ponds in North America are rarely constructed for food production. Sport fishing opportunities are of greater importance, but usually secondary to aesthetics. Therefore, extension effort directed to small water bodies is modest relative to other agricultural or natural resource management activities.

Within the North American context, a variety of institutions are involved in administering and managing small water bodies. These institutions are found at state, provincial, and federal levels. Departments and agencies involved in water management, pollution, wildlife, fisheries, conservation, land use, and public safety participate in impoundment management to varying degrees under varying circumstances. The degree that these entities work together dictates the success of many fishery programs. Therefore, the administrative and institutional setting is sufficiently diverse that only the broadest generalizations are possible when describing its organization and function.

Fisheries management of public or private impoundments is usually the responsibility of state agencies. These agencies provide services to land owners with private ponds frequently stipulating that the public benefits in some way, such as ensuring access. State services can include pre- and post-stocking checks, subsidized fish stocks, and fertilization, liming, and harvest information.

States are characteristically divided into fisheries districts, where two or more district biologists share research and management responsibilities. Research and management activities are often integrated in that a management strategy, once implanted, is evaluated and then modified until the range of results are defined. This adaptive approach to management is especially appropriate for agencies expected to provide fishery management advice specific to unique areas of the state.

Fishery management responsibilities of federal agencies in charge of public lands (i.e. the United States Forest Service and Bureau of Land Management) are usually restricted to habitat management, with the state agency setting harvest regulations, license fees, stocking restrictions, etc. The United States Fish and Wildlife Service is not currently involved in fisheries management of small water bodies although previously the Service provided sport fish for stocking. The United States Soil Conservation Service will assist with impoundment design. In some instances, cost sharing for pond construction is available through the United States Agricultural Stabilization and Conservation Service.

Fisheries research and extension activities are often conducted by land-grant universities through their departments of fisheries and natural resources. Fishery research on small impoundment fish populations continues to refine the principles defined by Swingle and Bennett. Land-grant institutions have a mandate to provide support to private pond owners through the federally-funded Cooperative Extension Service. University subject matter specialists backstop county-level extension agents who, in turn, provide on-site advice.

The traditional system for natural resource knowledge distribution in the United States and Canada involves a "trickle down" approach where problem definition originates within an agency or university. Research findings reach beneficiaries through extension publications and special interest groups. While this approach has been used with some success for decades, there is consideration being given to altering the process so that clients and user groups in general play a greater role in problem definition, i.e. participatory or "trickle up" information flow. The university or agency still translates the problem into theory and completes the research. The findings would then be submitted to user groups for critique. The process is adaptive to the extent that user groups are now part of the process and help assess the extent and under what conditions the research findings apply. The cycle is completed when new problems are defined by user groups and submitted for consideration.

The participatory approach has merit in that while research at the agency or university level is often by necessity narrowly defined, the evaluation by user groups is characteristically more broadly focused. In this process, cultural and social considerations become part of the evaluation, and ultimately become incorporated in the next round of problem solving. With this approach, lines of communication between agencies and user groups are often improved, resulting in a better informed and cooperative constituency.

4. REFERENCES

AFS (American Fisheries Society). 1985. Assessment and corrective management for fish populations in small impoundments. Special Publication No. 2. Texas Chapter of the American Fisheries Society.

_____. 1986. Stocking and management recommendations for Texas farm ponds. Special Publication No. 1. Texas Chapter of the American Fisheries Society.

Anderson, R.O. 1978. New approaches to recreational fishery management. Pages 73-90. *in* G.D. Novinger and J.G. Dillard, eds. New approaches to the management of small impoundments. North Central Division of the American Fisheries Society Special Publication No. 5. Dearborn, Michigan.

_____. 1983. Managing ponds for good fishing. Agricultural Guide Circular 9410. University of Missouri. Columbia, Missouri.

Arnoldi, D.C., J.B. Brantley, J.T. David, R.B. Davidson, M.S. Ewing, R.C. Gough, C.E. Hoenke, K.E. Lantz, J.S. Little, M.G. McElroy, T.P. Morrison, B.C. Reed, H.E. Rogillio, M.R. Walker, and M.G. Wood. 1990. Louisiana black bass fishery management plan (proposed). Louisiana Department of Wildlife and Fisheries, Baton Rouge, Louisiana.

Bardach, J.E., J.H. Ryther, and W.O. McLarney. 1972. Aquaculture: the farming and husbandry of freshwater and marine organisms. Wiley-Interscience, New York.

Bennett, G.W. 1943. Management of small artificial lakes, a summary of fisheries investigations 1938-42. Illinois Natural History Survey Bulletin 22:357-378.

_____. 1945. Overfishing in a small artificial lake. Illinois Natural History Survey Bulletin 23(3):373-406.

_____. 1951. Experimental largemouth bass management in Illinois. Transactions of the American Fisheries Society 80(1950):231-239.

_____. 1952. Pond management in Illinois. Symposium on farm fish ponds and management. The Journal of Wildlife Management 16(3):249-253.

_____. 1962. Management of artificial lakes and ponds. Reinhold Publishing Corp., New York.

Boyd, C.E. 1976. Fertilizing farm fish ponds. Highlights of Agricultural Research 23(2), Auburn University.

_____. 1982. Water quality management for pond fish culture. Elsevier Scientific Publishing Company, New York.

_____. 1985. Hydrology and pond construction. Pages 107-133. *in* C.S. Tucker, ed. Channel catfish culture. Elsevier Scientific Publishing Company, New York.

_____. 1990. Water quality in ponds for aquaculture. Alabama Agricultural Experiment Station. Auburn University, Alabama.

Boyd, C.E. and F. Lichtkoppler. 1979. Water quality management in pond fish culture. Alabama Agricultural Experiment Station Research and Development Series No. 22, Auburn University, Alabama.

Boyd, C.E. and M.L. Cuenco. 1980. Refinements of the lime requirement procedures for fish ponds. Aquaculture 21:293-299.

Carlander, K.D. 1977. Handbook of freshwater fishery biology. Volume 2. Iowa State University Press, Aimes, Iowa.

Davies, W.D. 1972. Progress report on the development of fisheries in Northeast Brazil. Project AID/csd-2270. International Center for Aquaculture, Department of Fisheries and Allied Aquacultures, Agricultural Experiment Station, Auburn University, Auburn, Alabama.

_____. 1987. Developing appropriate harvesting strategies for warmwater fish populations *in* southeastern United States. Pages 197-206. in Catch-and-release fishing: A decade of experience, Humbolt State University, Arcata, California.

_____. 1990. Managing fish populations in small impoundments. Pages 255-264. *in* R.O. Smitherman and D. Tave, eds. Proceedings: Auburn symposium on fisheries and aquaculture. Alabama Agricultural Experiment Station. Auburn University, Alabama.

Davies, W.D. and F. Rwangano. 1991. Farm pond fish populations in the Willamette Valley, Oregon: assessment and management implications. Pages 143-149. *in* J.L. Cooper and R.H. Hamre, coordinators. Warmwater fisheries symposium I. U.S. Department of Agriculture Forest Service Report RM-207. Fort Collins, Colorado.

Dendy, J.S. 1963. Farm ponds. Pages 595-620. *in* D.G. Frey, ed. Limnology in North America. University of Wisconsin Press. Madison, Wisconsin.

Dyche, L.L. 1911. Ponds, pond fish, and pond fish culture. State Department of Fish and Game, State Printing Office, Topeka, Kansas.

Embody, G.C. 1915. The farm fish pond. Cornell Reading Courses, Country Life Series 3, 4(94):213-252.

Everhart, W.H. and W.D. Youngs. 1981. Principles of fishery science. Cornell University Press, Ithaca, New York.

Fisher, W.L. and A.E. Grambsch. 1991. Measuring recreational fisheries values. Pages 343-349. *in* J.L. Cooper and R.H. Hamre, coordinators. Warmwater fisheries symposium I. U.S. Department of Agriculture Forest Service Report RM-207. Fort Collins, Colorado.

Gablehouse, D.W., Jr., R.L. Hager, and H.E. Klassen. 1982. Producing fish and wildlife from Kansas ponds. Kansas fish and Game Commission, Pratt, Kansas.

IDC (Illinois Department of Conservation). 1992. Management of small lakes and ponds in Illinois. Division of Fisheries, Springfield, Illinois.

IFG (Idaho Fish and Game). 1990. Fisheries management plan, 1991-1995. Department of Fish and Game, Boise, Idaho.

Jensen, J. 1984. Liming fish ponds. Alabama Cooperative Extension Service Circular ANR-232, Auburn, Alabama.

_____. 1985. Fertilizing fish ponds. Alabama Cooperative Extension Service Circular ANR-249, Auburn, Alabama.

_____. 1990. Managing ponds for better fishing. Alabama Cooperative Extension Service Leaflet YANR-90, Auburn, Alabama.

LeCren, E.D 1951. The length-weight relationships and seasonal cycle in gonad weight and condition in the perch, *Perca fluviatilia*. Journal of Animal Ecology 20(2):201-219.

Lovell, T. 1989. Nutrition and feeding of fish. Van Nostrand Reinhold, New York.

Marriage, L.D., A.E. Borell and P.M. Scheffer. 1971. Trout ponds for recreation. Farmers Bulletin No. 2249, U.S. Department of Agriculture, Washington, D.C.

Masser, M. 1992. Management of recreational fish ponds in Alabama. Alabama Cooperative Extension Service Circular ANR-577, Auburn, Alabama.

Modde, T. 1980. State stocking policies for small warmwater impoundments. Fisheries 5(5):13-17.

Modde, T. and C.G. Scalet. 1985. Latitudinal growth effects on predator-prey interactions between largemouth bass and bluegills in ponds. North American Journal of Fisheries Management 5:227-232.

Moyle, P.B. and J.J. Cech, Jr. 1988. Fishes, an introduction to ichthyology. Prentice Hall, Englewood Cliffs, New Jersey.

Murphy, B.R. and D.W. Willis. 1991. Application of relative weight (Wr) to western warmwater fishes. Pages 243-248. *in* J.L. Cooper and R.H. Hamre, coordinators. Warmwater fisheries symposium I. U.S. Department of Agriculture Forest Service Report RM-207. Fort Collins, Colorado.

Novinger, G.D. 1984. Observation on the use of size limits for black bass in large impoundments. Fisheries 9(4):2-4.

Pillai, V.K. and C.E. Boyd. 1985. A simple method for calculating liming rates for fish ponds. Aquaculture 46:157-162.

Piper, R.G., I.B. McElwain, L.E. Orme, J.P. McCraren, L.G. Fowler, and J.R. Leonard. 1982. Fish hatchery management, U.S. Department of Interior, Fish and Wildlife Service, Washington, D.C.

Reeves, W.C. and F.R. Harders. 1990. New approaches to managing public fishing lakes in Alabama. Pages 272-282. *in* R.O. Smitherman and D. Tave, eds. Proceedings: Auburn symposium on fisheries and aquaculture. Alabama Agricultural Experiment Station. Auburn University, Alabama.

Reynolds, J.B. and L.R. Babb. 1978. Structure and dynamics of largemouth bass populations. Pages 51-61.*in* G.D. Novinger and J.G. Dillard, eds. New approaches to the management of small impoundments. North Central Division of the American Fisheries Society Special Publication No. 5. Dearborn, Michigan.

Russey, G.R. n.d. How to grow trout in your back yard (or other unlikely places). Life Support Systems, Inc. Albuquerque, New Mexico.

Scheffer, P.M. and L.D. Marriage. 1975. Trout farming: Could trout farming be profitable. Soil Conservation Service Leaflet No. 552, U.S. Department of Agriculture, Washington, D.C.

Schlesinger, D.A. and H.A. Regier. 1982. Climatic and morpheodaphic indices of fish yields from natural lakes. Transactions of the American Fisheries Society 111:141-150.

SCS (Soil Conservation Service). 1971. Ponds for water supply and recreation. Agricultural Handbook No. 387. U.S. Department of Agriculture, Washington, D.C.

_____. 1982a. Ponds: planning, design, construction. Agricultural Handbook No. 590. U.S. Department of Agriculture, Washington, D.C.

_____. 1982b. Basic statistics: 1982 natural resources inventory. Statistical Bulletin 756. U.S. Department of Agriculture, Washington, D.C.

Swingle, H.S. 1949. Experiments with combinations of largemouth black bass, bluegills and minnows in ponds. Transactions of the American Fisheries Society 76:46-62.

_____. 1950. Relationships and dynamics of balanced and unbalanced fish populations. Agricultural Experiment Station, Alabama Polytechnic Institute, Auburn, Alabama.

_____. 1952. Farm pond investigations in Alabama. The Journal of Wildlife Management 16(3):243-249.

_____. 1956. Appraisals of methods of fish population study -part IV: Determination of balance in farm fish ponds. Transactions of the North American Wildlife Conference, Wildlife Management Institute, Washington, D.C.

_____. 1967. Warm water ponds for panfish. Pages 169-171. *in* Outdoors USA: The yearbook of Agriculture. U.S. Department of Agriculture, Washington, D.C.

Swingle, W.E. and E.W. Shell. 1971. Tables for computing relative conditions of some common freshwater fishes. Agricultural Experiment Station Circular 183. Auburn University, Alabama.

Weigmann, D.L. and L.A. Helfrich. 1992. Content analysis of the pond management literature. Fisheries 17(5):27-34.

Wenger, A. 1972. A review of the literature concerning largemouth bass stocking techniques. Texas Parks and Wildlife Department Technical Series No. 13. Sheldon, Texas.

White, C.E., Jr. 1990. Applications of Swingle pond analysis techniques by the Alabama Department of Conservation. Pages 265-269. *in* R.O. Smitherman and D. Tave, eds. Proceedings: Auburn symposium on fisheries and aquaculture. Alabama Agricultural Experiment Station. Auburn University, Alabama.

Willis, D.W. and C.S. Guy. 1991. Largemouth bass management in South Dakota: comparison with waters further south and east. Pages 336-342. *in* J.L. Cooper and R.H. Hamre, coordinators. Warmwater fisheries symposium I. U.S. Department of Agriculture Forest Service Report RM-207. Fort Collins, Colorado.

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